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ORIGINAL PAPER

Genotype × environmental interactions for analyzing adaptability and stability in different clones of *Dalbergia sissoo* Roxb.

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Abstract: In total 36 superior clones of *Dalbergia sissoo* Roxb., screened from 300 selections conducted in natural and growing range of India and Nepal, were multiplied using single nodal cuttings and established to evaluate genotype×environmental interactions for adaptability and stability at the age of 30 months in three geographical locations in the state of Punjab, India. Clone 124 had maximum adaptability and stability (*bi* = 1.04) to perform exceedingly well over the locations. Clones 36 and 1 were stable with mean regression coefficient of 0.84 and 1.22, respectively. Nonetheless, clone 41 performed exceedingly well for all the characters to attain maximum population mean, and the performance varied substantially across the locations. Therefore, clone 41 was considered as productive but non-adaptive clone. Though some of the clones were sensitive to sites, 14 clones for height, 16 for collar diameter, 12 for DBH and 7 for volume were relatively un-sensitive with higher regression coefficient. Nonetheless, clone 124 was the most stable with average *bi* value of 1.04 and productive, which could play an important role in future breeding and commercial deployment of stable and productive planting stock of *Dalbergia sissoo*.

Keywords: *Dalbergia sissoo* Roxb.; G×E interactions; stability parameters; adaptability; superior genotypes

Introduction

Dalbergia sissoo is an important multipurpose tree species, known for hard, strong and durable timbers exploited from both natural and plantation forests. It is distributed between latitude 21.17° N to 32.60° N, longitude 74.80° E to 93.43° E and altitude up to 900 m in the Sub-Himalayan tracts of India and planted across the countries (Tewari 1994). Though the species has a number of promising attributes, it exhibits poor form attributed to crooked and forked as well as stumbling blocks which deteriorates its timber quality. However, very high variability exists in its growing range, and it indicates possibility of genetic improvement.

In this research, the Forest Research Institute, Dehradun, India selected a number of plus trees of *Dalbergia sissoo* from entire geographical and distribution range of India and Nepal and cloned. Thereafter, a series of first generation seed orchards and gene banks were established in different states of the India. Though the species has number of promising attributes, it exhibits generally poor stem form (Bangarwa et al. 1990) and forked bole which deteriorates its timber quality. The species has recently been eclipsed with a serious disease called die-back, supposed to be caused by *Fusarium solani* and *Ganoderma lucidum*. The low to heavy mortality of trees are reported in major growing countries and trees of all age groups are prone to wilting and mortality (Shukla and Harsh 2010). In India, the disease was reported in entire northern growing regions (Dayaram 2003), and the losses to the tune of Rs.1000 crore (Shukla 2002). Therefore, the tree improvement programme was initiated to not only improve the productivity of the species but also address persisting problems of stem crookedness and die-back.

Nonetheless, there is large variability for stem forms in its natural distribution zone of the species, which indicates possibility of improvement through the selection and the multiplication. A preliminary selection was thus carried out for productive clones in different gene banks and clonal seed orchards, and established at geographical locations to test adaptability and stability through genotype-site interactions. The study of Genotype × environmental interaction for identification of stable genotypes could be recommended for commercial deployment, and could easily be utilized in future breeding programme. Such selected clones will increase the genetic gains and economic

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benefits substantially. However, only limited works on such lines were carried out in tree species and were advised to be broadened particularly in plantation crops (Yeiser et al. 1981; Barnes et al. 1984; Yu et al. 2003).

Materials and methods

The present study was carried out on 36 clones established during 2006 in the states of Punjab at Ludhiana (Longitude 75°59'11.4" E, Latitude 30°59'08.3" N, Altitude 260 m), Hoshiarpur (Longitude 75°49'02.3" E, Latitude 31°33'33" N, Altitude 247 m) and Patiala (Longitude 76°24'01" E, Latitude 30°19'36" N, Altitude 249 m). The preliminary selection of clones was carried out from existing seed orchards and gene banks adopting index method of selection (Cotterill and Dean 1986). In this way, 36 clones differing in morphological features, origin, growth and yield attributes were selected (Table 1), multiplied clonally and planting in three locations under completely randomized block design (RBD) with three replications (nine ramets in each replication). A uniform spacing of 3 m × 3 m was adopted at all experimental locations.

Table 1. Details of 36 clones evaluated for adaptability and stability over the geographical locations

S. No.	Clone No.	Source of origin	S. No.	Clone No.	Source of origin
1	1	Sabhalgarh, Chiriapur, Bijnor, Uttar Pradesh	19	124	Kosi River Bank, Inerwa, Sarali, Nepal
2	2	Sabhalgarh, Chiriapur, Bijnor, Uttar Pradesh	20	128	Mahendragarh, Sarali, Nepal
3	3	Trilokpur, Gonda, Bijnor, Uttar Pradesh	21	168	Kanau, Chaur, Chila, Pauri, Uttarakhand
4	4	Sabhalgarh, Chiriapur, Bijnor, Uttar Pradesh	22	174	Kanau, Chaur, Chilla, Pauri, Uttarakhand
5	9	Sabhalgarh, Pathri, Haridwar, Uttarakhand	23	192	Hasanpur 2, Tulsipur, Gonda, Uttar Pradesh
6	10	Sabhalgarh, Pathri, Haridwar, Uttarakhand	24	198	Hasanpur 2, Tulsipur, Gonda, Uttar Pradesh
7	12	Sabhalgarh, Pathri, Haridwar, Uttarakhand	25	201	Hasanpur 2, Tulsipur, Gonda, Uttar Pradesh
8	14	Sabhalgarh, Pathri, Haridwar, Uttarakhand	26	204	Hasanpur 2, Tulsipur, Northgonda, Uttar Pradesh
9	19	Shah Mansurpur,Saharanpur, Uttar Pradesh	27	232	Birpur 4, Bhambar,Gonda, Uttar Pradesh
10	24	C. B.Gange, Barielly, Uttar Pradesh	28	235	Bankatwa 2, Gonda, Uttar Pradesh
11	33	Bhainsasur, Tulsipur,Gonda, Uttar Pradesh	29	237	Bankatwa 2, Gonda, Uttar Pradesh
12	36	Hasanpur, Tulsipur, Gonda, Uttar Pradesh	30	243	Bankatwa 2, Gonda, Uttar Pradesh
13	41	Hasanpur, Tulsipur, Gonda, Uttar Pradesh	31	247	Bankatwa 2, Gonda, Uttar Pradesh
14	43	Trilokpur,Tulsipur, Gonda, Uttar Pradesh	32	5038	B.B.C 72-73 I/S, Sangrur, Punjab
15	49	Trilokpur,Tulsipur, Gonda, Uttar Pradesh	33	5039	Pir Mashala, Compt.- II, Dera Bassi, Patiala, Punjab
16	51	Birpur, Bhambar,Gonda, Uttar Pradesh	34	5040	Amargarh-Chaunda Road, Km 6-7 L/S Sangrur, Punjab
17	57	Dinsia, Khalawala, Ambala, Haryana	35	5041	G.B.C 194-95 R/S Leharganga, Sangrur, Punjab
18	66	Chihrauli, Yamunagar, Haryana	36	5042	Bir Mattewara Compt. 25, Ludhiana, Punjab

Stability analysis

The final growth performance was measured at 30 months for plant height, height at first branch, collar diameter (CDM), diameter at breast height (DBH), stem straightness, branching behaviour and volume. The analysis of stability was carried out as per Eberhart and Russel (1966) using INDOSTAT statistical package. A total of 36 clone(t) were tested in three environments(s) for stability analysis and considering Y_{ij} as the mean observation of i^{th} clone in j^{th} environment, the stability model as per following equation was adopted;

$$Y_{ij}=\mu_i + \beta_i I_j + \delta_{ij} \tag{1}$$

Where, Y_{ij} is mean growth performance of ith clone at jth geographical location (i = 1, 2..., t and j =1, 2, …, s). μ_i is mean of all the clones over all the sites. β_i is regression coefficient of ith clone on environmental index which measures the response of varying geographical locations. I_j is environmental index which was defined as the deviation of the mean of all the clones at a given geographical location from overall mean. δ_{ij} is error effect.

$$I_j = \frac{\sum_i Y_{ij}}{t} - \frac{\sum_i \sum_j Y_{ij}}{ts}, \text{ with } \sum_j I_j = 0 \tag{2}$$

Where, t= clone, ts= growth period,

The model was preferred over other stability models, as in this model not only the regression coefficient as first measure of stability was considered, but also its further calculated function of deviation for regression mean square as a second measure. Therefore, two parameters of stability were calculated in following manner.

Regression coefficient

The regression coefficient which was the regression of the performance of each clone under different environments on the environmental means over all the clones. This was estimated as follows:

$$b_i = \frac{\sum_j Y_{ij} I_j}{\sum_j I_j^2} \tag{3}$$

where, $\sum_j Y_{ij} I_j$ is the sum of products, and $\sum_j I_j^2$ is the sum of square

Mean square deviations (S^2d)

Mean square deviations (S^2d) from linear regression were calculated as following formulae:

$$S^2 d = \frac{\sum_j \delta_{ij}^2}{(s-2)} - \frac{S_e^2}{r}$$

$$\sum_j \delta_{ij}^2 = \left[\sum_j Y_{ij}^2 - \frac{Y_i^2}{t}\right] - \frac{(\sum_j Y_{ij} I_j)^2}{\sum_j I_j^2} \quad (4)$$

where, S^2e is the estimate of pooled error.

In the analysis, following computational steps were involved:

Computation of environment of index (I_j)

$$I_j = \frac{\sum_j Y_{ij}}{t} - \frac{\sum_i \sum_j Y_{ij}}{ts}$$
$$= \frac{\text{Total of all the varieties at } j\text{th location}}{\text{Number of varieties}} - \frac{\text{Grand total}}{\text{Total number of observations}} \quad (5)$$

Computation of regression coefficient

Computation of regression coefficient (b_i) for each clone:

$$b_i = \frac{\sum_j Y_{ij} I_j}{\sum_j I_j^2} \quad (6)$$

where, $\sum_j I_j^2$ is the constant for all the treatments, $\sum_j Y_{ij} I_j$ is the sum of product of environmental index (Ij) with corresponding mean ($\overline{X}$) of that clone at each location, which were obtained as followings:

$$[\overline{X}][I_j] = [\sum_j Y_{ij} I_j] = [S] \quad (7)$$

where, $[\overline{X}]$ is the matrix of means, $[I_j]$ is the vector for environmental index, and $[S]$ is the vector for sum of products, i.e., $\sum_j Y_{ij} I_j$.

Computation of S^2d

In a regression analysis variance of dependent variable (Y) was partitioned into two parts : one explained the linearity between dependent and independent variables (variance due to regression), and the other explained the variance due to deviation from linearity.

Symbolically as follows:

$$\delta_y^2 = \delta^2 \text{regression} + \delta^2 \text{deviation from the regression} \quad (8)$$

Obviously, by subtracting the variance due to regression from δ_y^2 , the variance due to deviations from regression which in turn was used for estimated S^2d values. The variance of means over different environment with regard to individual clone was obtained as follow:

$$\sigma_{Vi}^2 = \sum_j Y_{ij}^2 - (\frac{Y_i^2}{t}) \quad (9)$$

Then, the variance due to deviation from regression was calculated as per following formula:

$$\sum_j \delta_{ij}^2 = \left[\sum_j Y_{ij}^2 - \frac{Y_i^2}{t}\right] - \frac{(\sum_j Y_{ij} I_j)^2}{\sum_j I_j^2} \quad (10)$$

Where, $\sum_j Y_{ij}^2 - \frac{Y_i^2}{t}$ is the variance due to dependent variable; $\frac{(\sum_j Y_{ij} I_j)^2}{\sum_j I_j^2}$ is the variance due to regression; $\sum_j Y_{ij} I_j$ is *bi*.

Variance analysis

The skeleton for analysis of variance for stability parameters was carried as per following skeleton suggested by Eberhart and Russel (1966).

Source of variation	**Degree of freedom**
Genotypes (G)	*g*-1
Environment (E) + Interaction (G×E)	*g* (*e*-1)
Environment (linear)	1
G×E (linear)	*g*-1

Pooled deviations	$g(e\text{-}2)$
Genotype 1	e-2
Genotype 2	e-2
⋮	⋮
Genotype g	e-2
Pooled error	$ge\ (r\text{-}1)$

g, e, and r represent the numbers of genotypes, environments and replication, respectively.

Stable genotypes

A clone with regression coefficient (b=1) and the deviation not significantly different from zero was the stable one included.

Mean and standard error of 'b'

$$\bar{b} = \frac{\sum_i b_i}{v} \tag{11}$$

where, $\bar{b}$ is the mean of b.

$$S.E.(b) = \sqrt{\frac{M.S.\text{ due to pooled deviation}}{\sum_i I_j^2}} \tag{12}$$

Similarly,

$$S.E.(bi) = \sqrt{\frac{M.S.\text{ due to pooled deviation of } i\text{th clone}}{\sum_i I_j^2}} \tag{13}$$

where, *M.S.* due to pooled deviation of *i*th clone is $\frac{\delta_{ij}^2}{s-2}$ with (s-2)*df*.

Population mean

Population mean (μ) and standard error (*S.E.*) was calculated as following formulae:

$$\text{Population mean} = \frac{\text{Grand total}}{\text{Number of observations}} \tag{14}$$

$$S.E.(mean) = \sqrt{\frac{M.S.\text{ due to pooled deviation}}{\text{Number of environments - 1}}} \tag{15}$$

Indexing of clones

The indexing of clones was conducted based on *bi* and S^2d values in following manners:

S. No.	Parameters	*bi* values
a	Sensitive	>1.50
b	Stable	0.50–1.50
c	Adaptable	<0.50

Based on population mean, the stable clones were further divided as “Stable and productive” and “Stable but non-productive”.

Results

The growth performance of 36 clones at the age of 30 months was analyzed in individual and pooled manner for all three geographical locations to calculate G×E interactions. The maximum mean height (416.76 cm), DBH (43.03 mm) and volume (0.14 cm^3) were recorded for Patiala, but the clones attained maximum collar diameter (58.26 mm) at Ludhiana (Table 2). However, the values for all the traits were recorded minimum at Hoshiarpur over pooled mean. Clone 41 performed exceptionally well for all the traits to the extent of 29.73%, 27.76%, 32.25% and 100% higher for height, collar diameter, DBH and volume over pooled mean, respectively. Clone 243 was found to be the least performer across the locations (Table 3). The pooled ANOVA shows that variation due to clones for all the characters is highly significant (Table 4). The variation due to environment is highly significant. Similarly, the variation due to environment and clone-environment interactions is also significant except collar diameter. The stability for different characters was analyzed and presented hereunder.

Table 2. Mean performance of different clones at various geographical locations

Location	Height (cm)	Collar diameter (mm)	Diameter at breast height (mm)	Volume (cm^3)
Ludhiana	380.65	58.26	42.83	0.13
Hoshiarpur	306.96	47.02	29.59	0.08
Patiala	416.76	56.04	43.03	0.14
Pooled mean	368.12	53.77	38.48	0.14
Minimum	126.310	17.870	11.920	0.000
Maximum	477.210	68.700	50.890	0.280
Standard deviation	74.000	11.418	9.714	0.071
CV (%)	20.118	21.235	25.244	51.530

Height

The *bi* values (Table 5, Fig. 1) depicted that nine clones were found to be stable, 15 clones were sensitive and 12 clones were resistant to the environment. Out of the ten stable clones, seven (1, 9, 24, 36, 51, 124 and 198) were stable and productive which recorded greater height than the population mean. Whereas, two clones (192 and 5040) were found stable but non-productive with less height than the population mean.

Table 3. Clonewise population pooled means for 36 clones planted over three locations

S. No.	C. No.	Height (cm)	Collar diameter (cm)	DBH (cm)	Volume (cm^3)	S. No.	C. No.	Height (cm)	Collar diameter (cm)	DBH (cm)	Volume (cm^3)
1	1	394.73	57.37	42.30	0.13	19	124	438.35	59.07	45.80	0.17
2	2	438.47	62.70	47.35	0.15	20	128	398.49	60.51	43.75	0.16
3	3	432.76	65.25	49.26	0.28	21	168	382.01	55.34	39.48	0.06
4	4	404.13	61.47	45.43	0.19	22	174	351.59	48.27	37.06	0.08
5	9	404.16	51.15	37.19	0.12	23	192	303.92	44.00	27.67	0.12
6	10	356.42	56.65	41.57	0.16	24	198	375.13	52.53	37.01	0.11
7	12	414.47	37.31	20.91	0.06	25	201	429.38	60.51	45.03	0.23
8	14	257.71	61.31	44.29	0.11	26	204	204.76	28.27	16.21	0.02
9	19	413.80	62.34	46.13	0.22	27	232	293.98	40.78	26.41	0.11
10	24	430.92	61.76	44.68	0.16	28	235	401.40	57.18	39.91	0.11
11	33	427.77	63.92	46.33	0.22	29	237	398.93	61.95	45.96	0.22
12	36	434.60	68.05	49.13	0.22	30	243	126.31	17.87	11.92	0.00
13	41	477.21	68.70	50.89	0.26	31	247	366.03	51.30	36.35	0.06
14	43	410.90	58.21	42.86	0.19	32	5038	366.76	63.27	42.34	0.17
15	49	419.95	62.31	45.53	0.22	33	5039	306.05	45.06	30.85	0.04
16	51	388.71	53.66	38.91	0.12	34	5040	335.7	51.87	37.17	0.13
17	57	365.87	51.36	38.57	0.13	35	5041	320.7	52.17	38.58	0.03
18	66	230.40	30.23	17.12	0.04	36	5042	339.51	52.01	35.42	0.16

Table 4. Pooled analysis of variance table for different characters over the geographical locations

Source of Variations	Degree of freedom	Mean sum of squares			
		Height	Collar diameter	Diameter at breast height	Volume
Clones	35	16501.95***	391.13**	283.13**	0.00***
Environment + (Clone×Environment)	72	11204.49**	251.68	209.41*	0.00**
Environments	2	112745.05***	1276.54**	2136.14***	0.03***
Clone×Environment	70	8303.33*	222.40	154.36	0.00*
Pooled Deviation	36	4517.08	160.20***	106.37***	0.00*
Pooled Error	210	2207.87	56.62	41.98	0.00
Total	107	12937.30	297.30	233.52	0.00

Significance level: ***p<0.001, **p<0.01, *p<0.05

Table 5. The *bi* and S^2di values calculated for adaptability and stability analysis among different clones

S. No.	C. No.	*bi* Value				S^2di Value			
		Height	Collar diameter	DBH	Volume	Height	Collar diameter	DBH	Volume
1	1	0.69	1.08	0.80	0.79	2040.25	17.43	43.25	0.000
2	2	2.70	2.69	2.34	2.65	-2387.74	78.39	-15.13	0.000
3	3	3.27	4.12	3.13	3.66	-1683.85	300.2*	86.26	0.001
4	4	2.23	3.07	2.32	2.28	-2372.98	-26.47	-42.84	-0.00
5	9	0.95	0.88	0.72	0.69	-2335.3	-62.59	-51.39	-0.00
6	10	1.98	2.7	2.02	1.92	-1283.6	-65.14	-51.79	-0.00
7	12	-0.06	-1.64	-0.83	-0.53	5849.19	-54.69	43.38	-0.00
8	14	-0.4	-0.58	0.05	-0.61	-684.94	113.26	64.39	-0.00
9	19	2.70	3.55	2.47	2.84	-2541.08	70.17	-14.64	-0.00
10	24	1.27	2.09	1.70	1.63	7323.13	100.13	108.74	0.002
11	33	2.06	2.38	2.16	2.34	-1972.44	58.89	23.49	-0.00
12	36	1.41	1.07	1.18	1.52	22.28	23.77	36.73	0.001
13	41	2.42	2.67	2.31	2.61	-1024.54	9.44	-28.06	-0.00
14	43	2.03	2.79	2.25	2.27	-2128.74	75.44	-13.98	-0.00
15	49	2.33	3.09	2.47	2.51	-2528.12	49.69	-20.65	-0.00
16	51	1.03	1.51	1.12	0.93	3305.35	57.93	55.4	0.000

Continue Table 5

S. No.	C. No.	*bi* Value				S^2di Value			
		Height	Collar diameter	DBH	Volume	Height	Collar diameter	DBH	Volume
17	57	1.74	2.36	1.74	1.51	-507.37	-66.58	-43.52	-0.00
18	66	-0.17	-1.38	-0.7	-0.37	3640.03	-62.16	-4.63	-0.00
19	124	1.01	1.14	1.08	0.96	-2548.83	-66.98	-49.1	-0.00
20	128	1.95	3.12	2.21	2.01	2464.74	-63.11	-36.3	0.000
21	168	-0.69	-0.49	-0.33	-0.89	-943.65	467.71**	23.52*	0.001
22	174	0.31	-0.46	0.39	-0.07	-2529.69	-37.14	66.01	-0.00
23	192	0.58	-1.71	-0.3	0.05	22716.6***	118.92	236.69*	0.000*
24	198	0.80	1.15	0.80	0.63	-1941.35	36.59	-23.04	-0.00
25	201	2.61	2.97	2.20	2.74	-2168.32	-31.07	-47.52	-0.00
26	204	-0.77	-1.98	-1.35	-0.79	-1729.88	-25.68	-41.09	-0.00
27	232	0.25	-1.95	-0.67	-0.18	25702.6**	208.94*	279.68*	0.00*
28	235	0.47	0.07	0.11	0.03	-2565.59	-12.89	-34.04	-0.00
29	237	1.77	1.58	1.60	1.80	1682.41	253.78*	191.06*	0.000*
30	243	-3.7	-5.11	-2.68	-2.00	7352.03	-0.75	-51.8	-0.00
31	247	-0.32	0.27	0.34	-0.39	5216.76	232.29*	239.17*	0.002
32	5038	1.78	2.29	2.00	1.79	-2595.44	-47.44	-48.45	-0.00
33	5039	-0.04	1.01	0.56	0.06	8951.46*	258.76*	213.81*	0.000*
34	5040	1.14	1.3	1.35	1.01	-1919.46	-67.00	-51.72	-0.00
35	5041	-1.08	-0.65	0.15	-0.88	13844.87*	1414.09***	608.81***	0.000**
36	5042	1.76	0.97	1.32	1.48	-1081.25	95.78	93.43	0.001

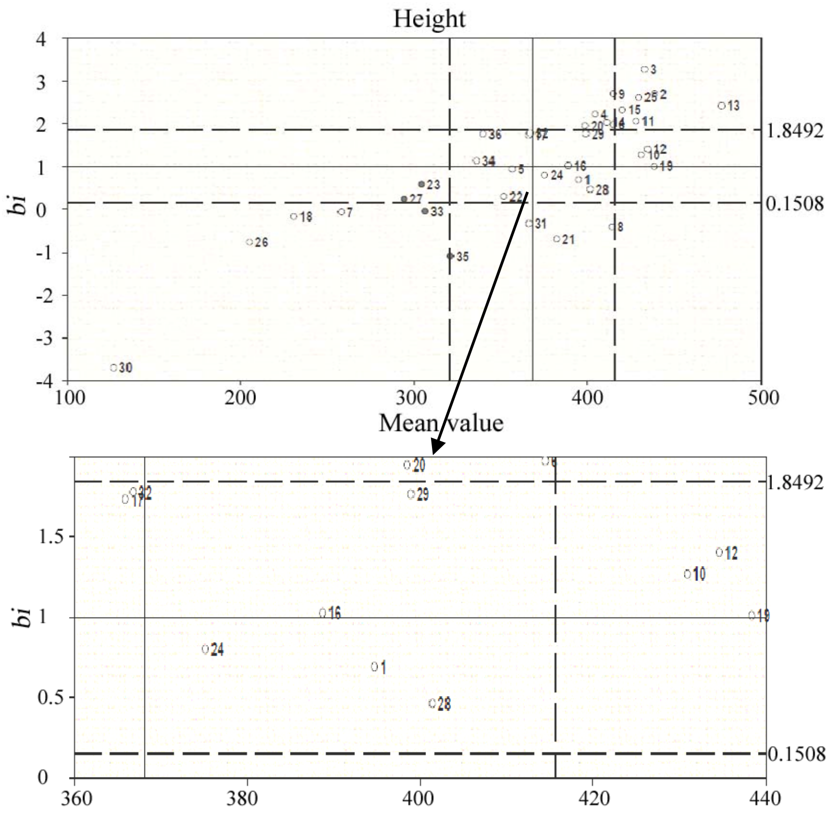

Fig. 1 Stability graph and exploded view for height

Collar diameter

Based on *bi* values (Table 5, Fig. 2), eight clones were found to be stable, sixteen were sensitive and twelve were resistant to the environment. Out of the eight stable clones, three clones (1, 36 and 124) were stable and productive with more collar diameter than population mean. Whereas, five clones (9, 198, 5039, 5040 and 5042) were stable but non-productive.

DBH

The *bi* values (Table 5, Fig.3) illustrated that nine clones were

stable, 15 clones were sensitive and 12 clones were adaptable to the environment for DBH. Of stable clones, 1, 36, 51 and 124) stable and productive with higher DBH than the population mean. The rests of five clones were stable but nonproductive.

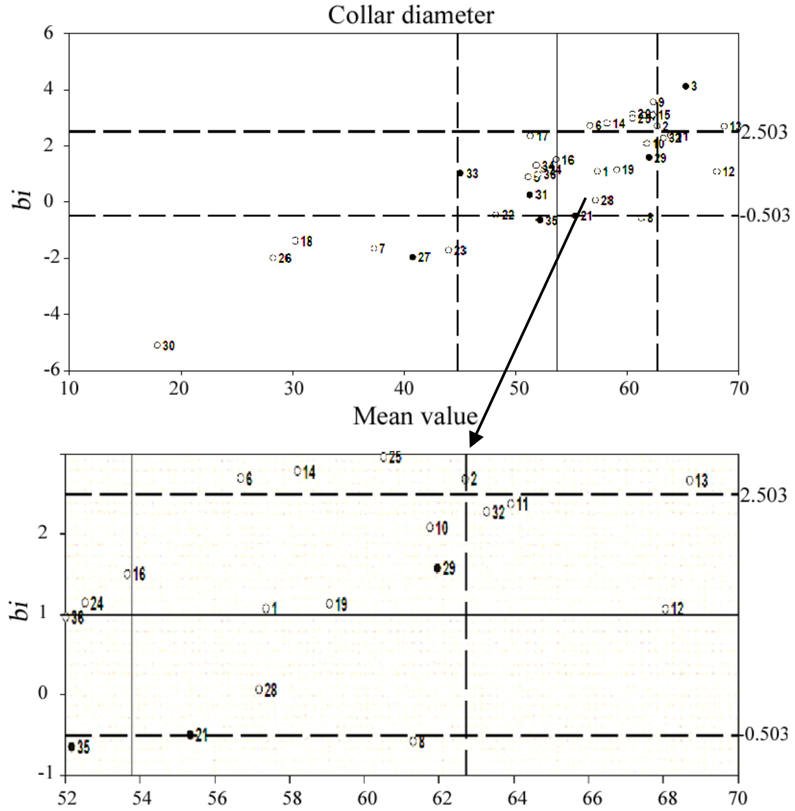

Fig. 2 Stability graph and exploded view for collar diameter

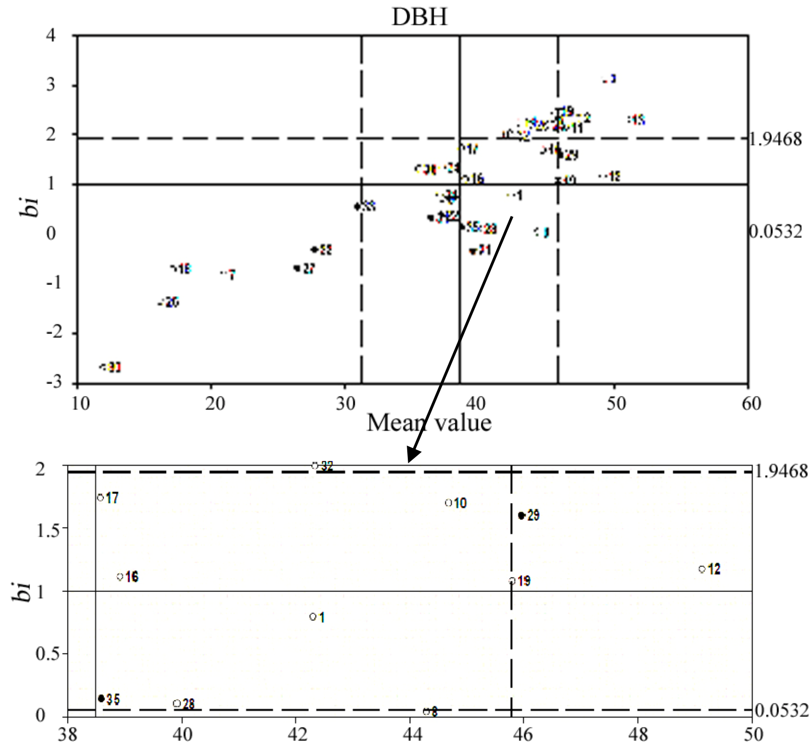

Fig. 3 Stability graph and exploded view for DBH

Volume

The *bi* values calculated for volume (Table 5, Fig. 4) indicated that 7 clones were stable, 16 were sensitive and 13 were resistant to the environment. Two clones (124 and 5042) were found to be stable and productive and rests of the clones were stable but nonproductive.

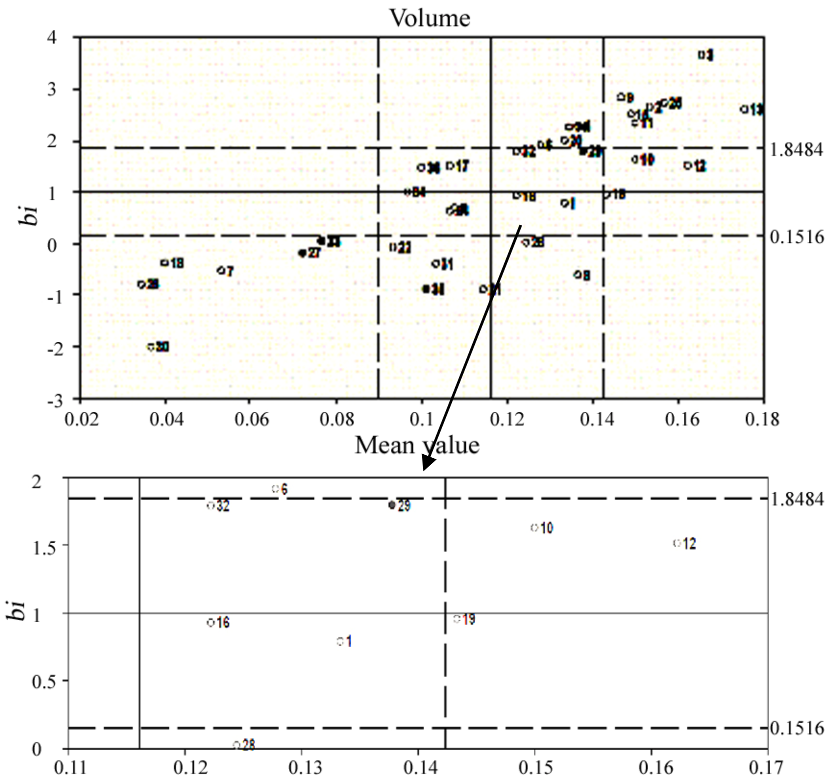

Fig. 4 Stability graph and exploded view for volume

Discussion

It is well known that the performance of different genotypes related with themselves varies according to the environment. The genotypes that are superior in one environment may not be correspondingly superior elsewhere. In a breeding stage, the contribution of environments in generating interaction was studied by Burdon (1977). The height was considered for study in different environments to calculate genetic correlations among the environments, which represented a powerful and flexible statistical concept for forest tree breeding. The stability for expression of performance of a particular trait could become one of the most desirable aspects of a genotype (clone/progeny) to be grown commercially, and it could be possible when the genotypes are comparatively evaluated under varying environments for many years. If the variance due to genotype×environment interaction is found significant, there are numbers of approaches to measure the stability for a particular trait in genotypes. In this way, different clones and progenies with highest genetic worth to a specific location can easily be identified (Otegebeye 1998).

Abdul-Latib et al. (2007) assessed the growth performance of selected *Acacia* species in provenance trials. The research results suggested that variation between species, adapted provenances and regions were important estimates or criteria for selection for appropriate sources to be used in tree improvement and breeding programme on sites that share similar environmental conditions. Bhatnagar et al. (1994) estimated stability parameters for yield of nine varieties across six environments in predominant soybean growing region of central India. The variety JS 71-05 was identified as a stable yielder, which exhibited almost unit regression coefficient with non-significant and lowest deviation from regression, and the highest and mean yield. In fact, the variety also possessed high degree of tolerance to pod shattering with practically no post-harvest yield losses.

To assess the stability and performance of ten varieties of field pea (*Pisum sativum*), Toklu et al. (2009) used uni-variate and multivariate methods to analyze genotypic, environmental, GE interactions for grain yield and plant characters. Ching and Hinz (1978) assessed height and DBH of 20 years old trees in 14 seed sources of Douglas-fir and analyzed at ten sites. The statistically

significant differences were reported among the traits studied in various parameters along with significant seed-source×planting-site (G×E) interactions. Rawat and Nautiyal (2007) reported significant genotype×site interaction for growth, physiological and biochemical parameters in different clones of *Dalbergia sissoo*. The variability estimated for these characters also indicated strong genetic control than the environment.

In the present investigation, 36 clones were tested for stability and adaptability over three locations in the state of Punjab, India. The clones were analyzed for regression coefficient (*bi*) and deviation from regression against the test means for height, collar diameter, DBH and volume. The clone 124 showed perfect adaptability and stability (*bi* = 1.04), which indicated that it performed equal well over the locations. Among 36 clones, though the clone 41 performed exceeding well for all the characters to attain maximum population mean, the performance varied substantially across the locations Therefore, the clone 41 was considered as productive but non-adaptive clone. The results of the present investigation were in agreement with the strategy on adaptability suggested by Finlay and Wilkinson (1963). The performance and adaptability analysis was carried out by plotting *bi* values of 36 clones against the mean values for individual traits as per Prabhakaran and Jain (1994), and the analysis results could become an aid in selecting a particular genotype for deploying commercially. In long gestation species like *Dalbergia sissoo*, it is imperative to grow stable genotypes that might have average productivity over productive but non-stable genotypes. Though not much work has been done in forest tree species, similar recommendations has been made in *Gossypium hirustum* by many researchers. The stable hybrids might be poor performers, and fall below average responsiveness would be favorable to grow in poor environments (Nizam et al. 1988; Tuteja et al. 1999; Nehra and Bhunia 2002; Tuteja 2006). Similarly, Clair and Kleinschmit (1986) emphasized that the information could be important to distinguish the genotypes for specific environments. It is also suggested that if the number of genotypes studied are sufficiently large and the environmental range is broad, the linear regression using the mean of all genotypes will becomes a valid tool to find the adaptive and stable genotypes (Fripp and Caten 1971).

On the other hand, 15 clones for height, 6 for collar diameter, 15 for DBH and 16 for volume production appeared to be sensitive or unstable, as the mentioned clones had higher regression coefficient. The clones were sensitive to sites and performed well only at favorable locations. Rana et al. (2006) supported similar results in *Pisum sativum* for pod yield, and the genotypes adapted to more favorable growing conditions manifested the high mean performance compared to grand mean with high *bi* values, but they could not performance under unfavorable conditions.

The stability of a genotype over a range of environments was measured by the mean square deviations from the regression (Eberhart and Russell 1966), the regression of its mean to an environmental index (Finlay and Wilkinson 1963) or combinations of both these parameters. The accuracy of yield prediction of a genotype in different environments is equally important in forest tree improvement, which was measured by the mean square deviations (S^2di) from the regression line. Clones, which possessed high mean (general mean plus two SE), only were considered for classification and characterization for adaptability as suggested by Cavalcanti and Gurgel (1973). Based on stability and productivity criteria adopted for each clone individually, an indexing was developed to found that clone 124 was not only most stable clone, but also most productive for all the characters with average *bi* value of 1.04 followed by clone 1 and clone 36 with average *bi* values of 0.84 and 1.22, respectively. As suggested by Arshad and Choudhary (2003), the genotype had values for the traits under study combined with a low degree of fluctuations under diverse environments. The clones possessed high means over grand mean accompanied by unit regression coefficient. The results were in agreement with Prakash (2006) for grain yield in *Cicer aretinum*. The present investigation supports the conclusion made by Koo et al. (2007), and the adaptability should not only be the criterion for selecting superior genotypes, but also include ample consideration for growth performance and regression coefficient.

Conclusion

The study provided useful information to screen productive and stable clones for large scale deployment and also make a clearer strategy for the breeding of *Dalbergia sissoo*. Clones 124, 36, and 1 were observed to be most stable and performed well in all the locations, and could be deployed commercially. Though four clones were not showing greater stability, they were reported to be promising for better growth performance and exhibited high mean values with unit regression coefficient. The results of the investigation would play an important role in increasing productivity of *Dalbergia sissoo* and enhancing income of the planters.

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